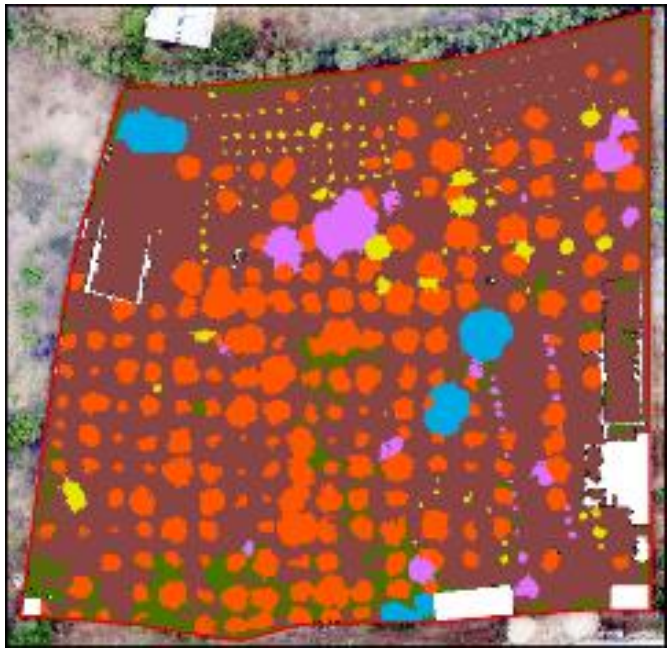
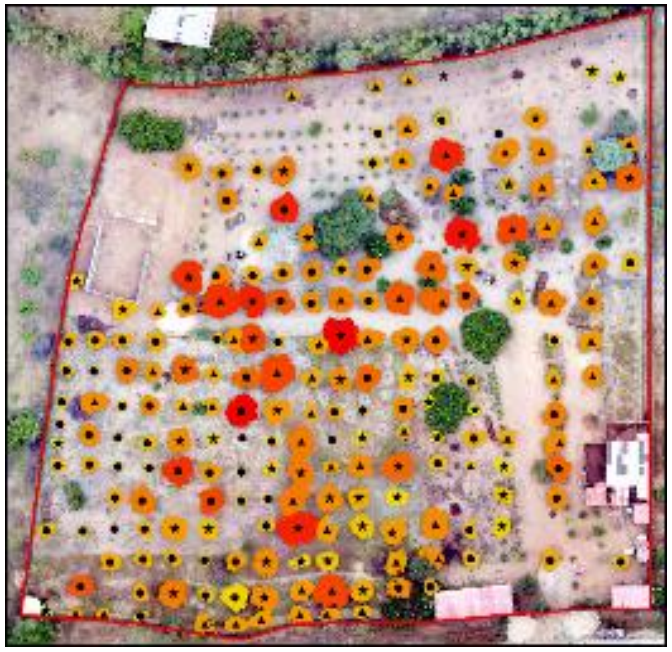
Plant diversity and productivity in Senegalese mango orchards: evidences from UAV photogrammetry

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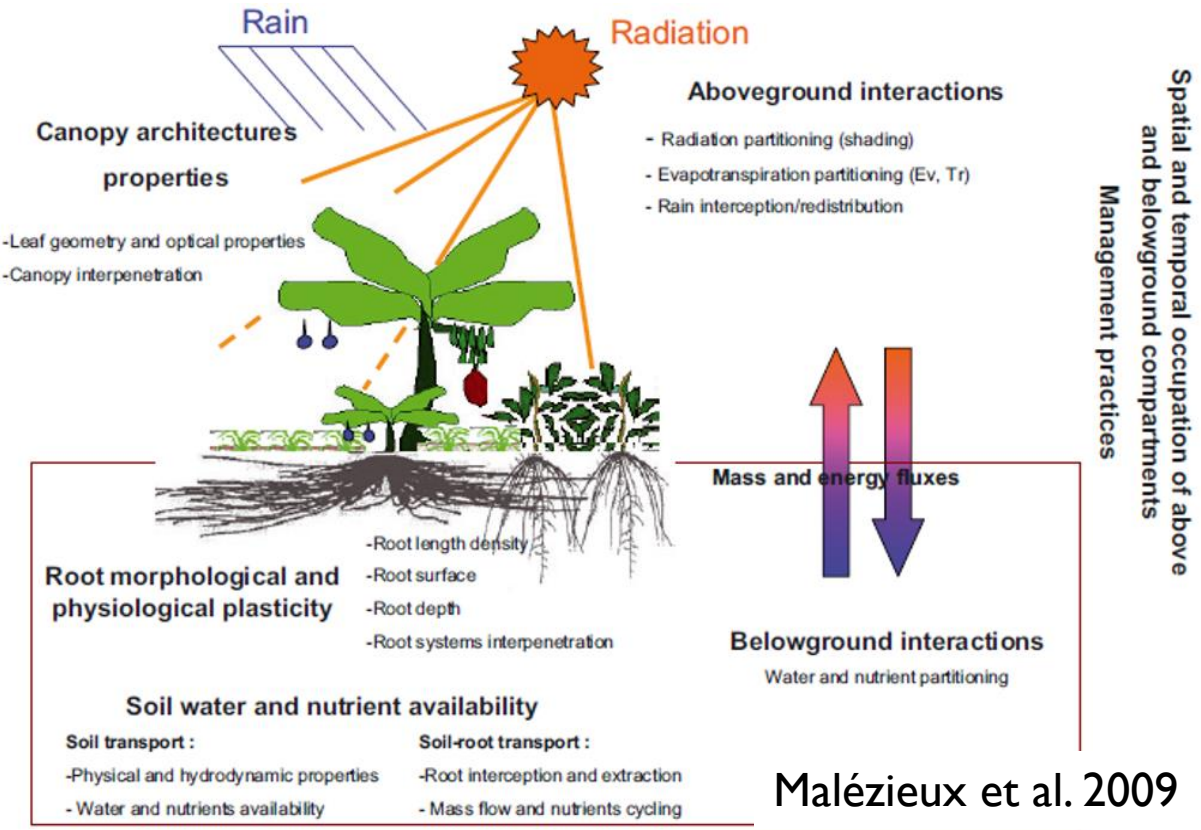
Plant diversity and productivity

Mixing plant species

increase overall productivity - pest & disease control - ecological services - economic profitability

(Malézieux *et al.* 2009)

Poplar-cereal intercropping, C. Dupraz



Malézieux et al. 2009

Complex interactions between field structure and productivity

- Plant diversity: species abundance, spatial arrangement, functional traits, etc.
- Productivity: land-sparing vs. land-sharing debate (Grass *et al.* 2019)

Spatial characterization

Agroforestry systems in tropics

Humid and semi-arid tropics

Mainly smallholders
Role in food security
Resilience to climate change

Productivity

Variable and context-dependent

Woody perennials with crop in West Africa (Felix *et al.* 2018)

Cocoa agroforest
(Deheuvels *et al.* 2012; Jagoret *et al.* 2017)

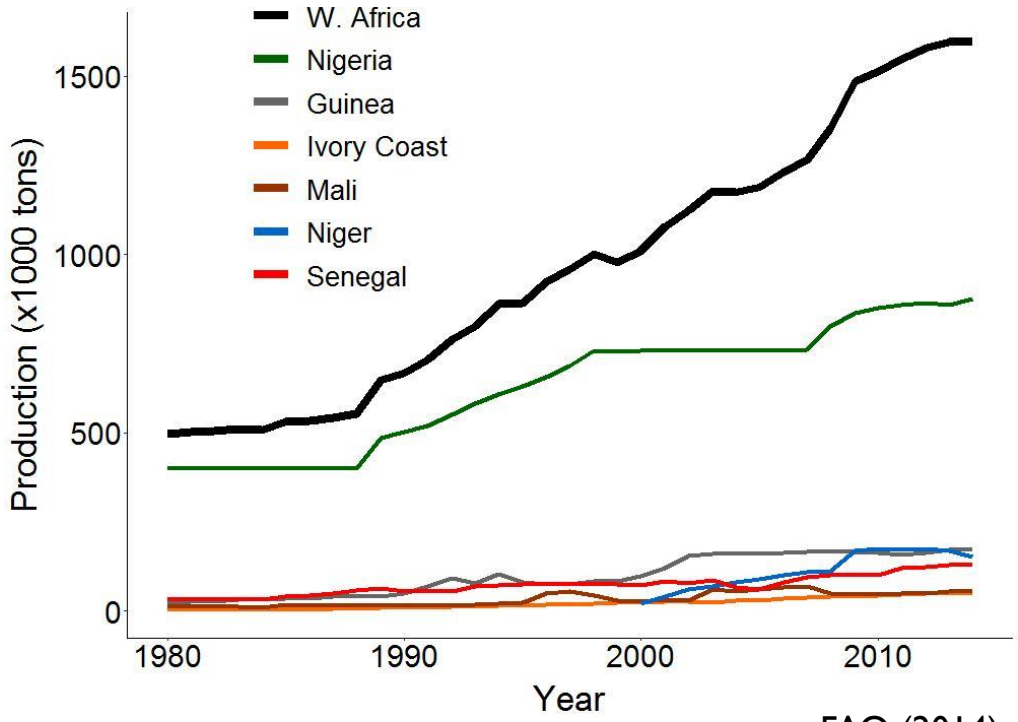
Few studies on fruit-based system

Mango production

Increasing production…

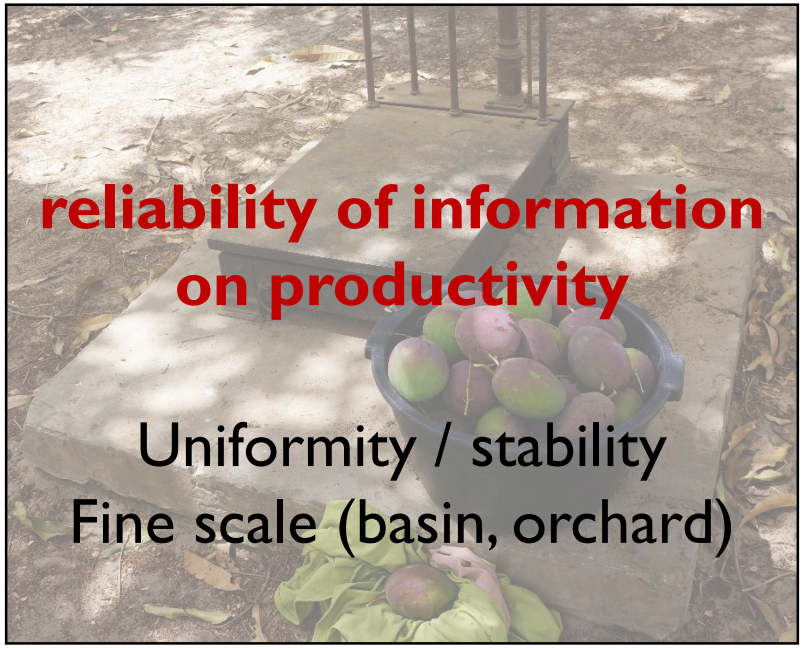
World = 50 Mt, West Africa = 1.6 Mt (FAO 2014)
→ majority in smallholder orchards

… but multiple constraints



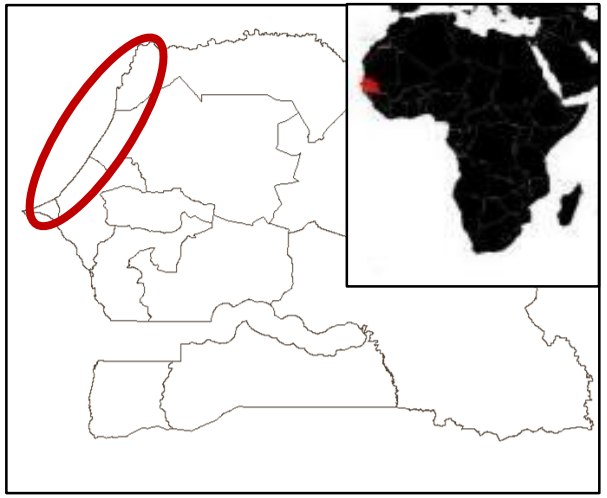
FAO (2014)

biotic, abiotic stresses



mango phenology
(alternance, asynchronism)

Case study: the Niayes region (Senegal)



High heterogeneity of cropping systems (Grechi *et al.* 2013)
→ **yield**

→ **No information at orchard scale**

medium ?

Agroforestry
Intercropping

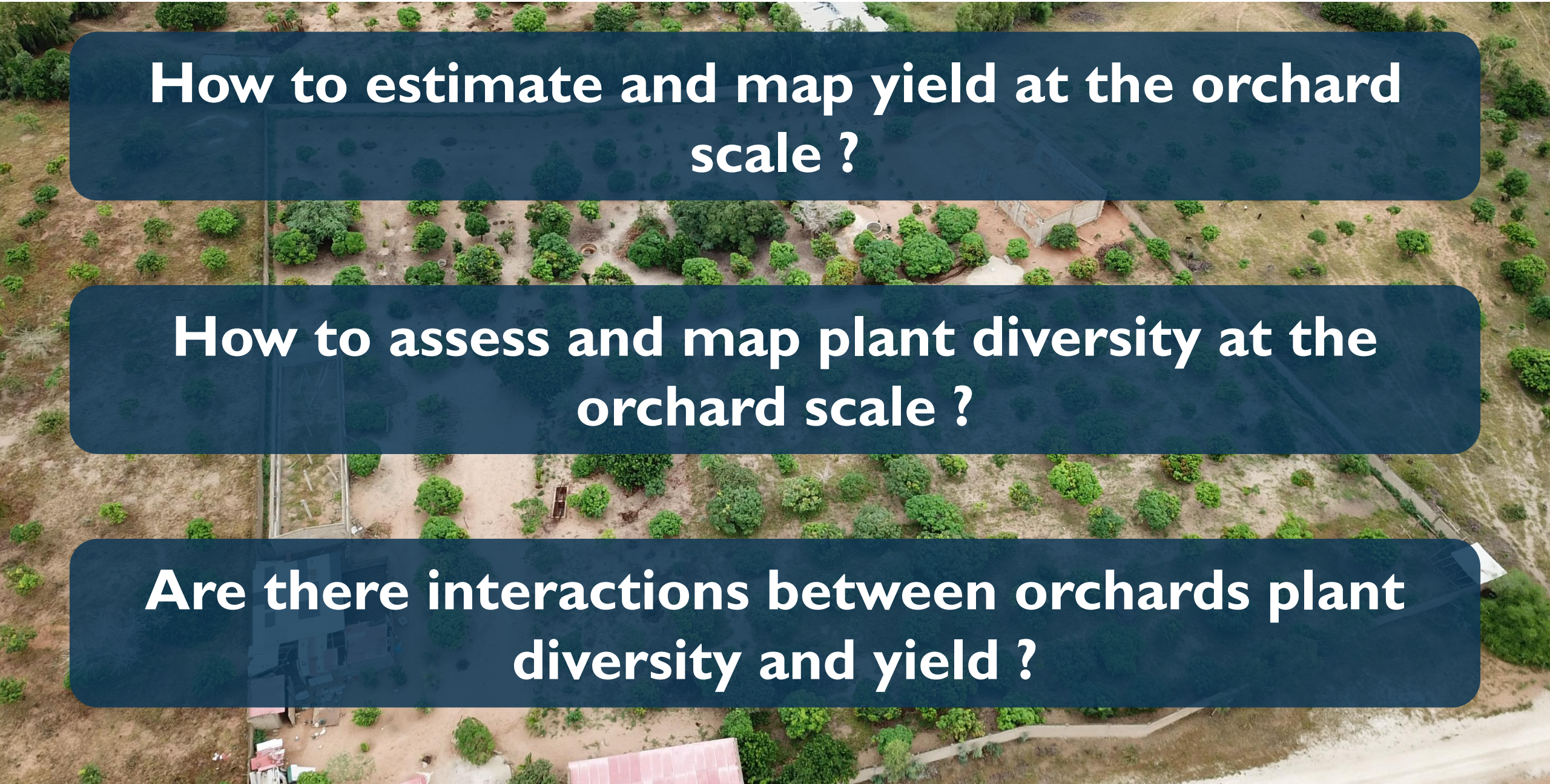
low ?

Extensive
Traditional

high ?

Intensive – export
Monocultivar

Questions



How to estimate and map yield at the orchard scale ?

How to assess and map plant diversity at the orchard scale ?

Are there interactions between orchards plant diversity and yield ?

Methods for orchard characterization

Diversity ? **Yield ?**

Field survey

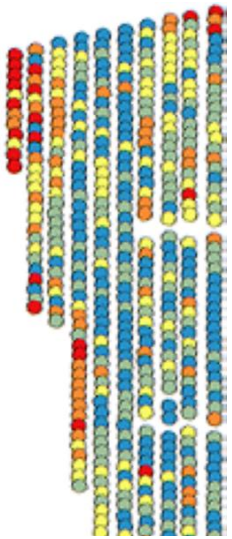
diversity sampling, manual yield estimation, producer survey

Remote sensing

machine vision system *(Gongal et al., 2015)*, satellite imagery

Mechanistic models

Shrimp, Stein et al. 2016



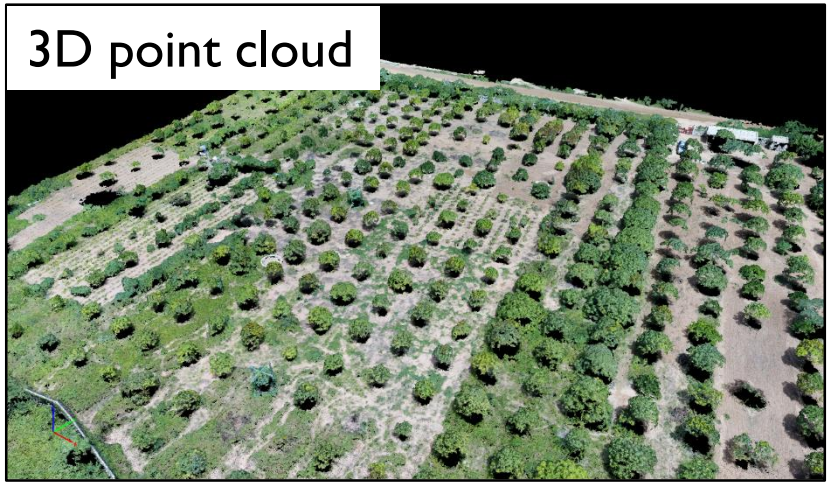
WV, Anderson et al. 2018

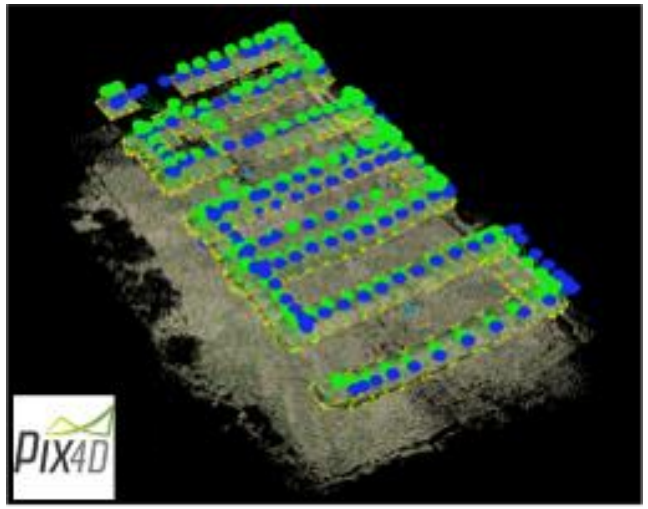
Limitation in mango orchards

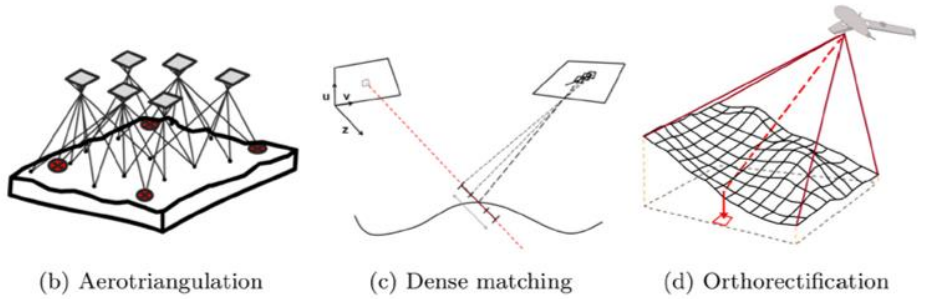
- Reliability and precision
- Remote sensing adaptability to complex cropping systems
- No existing mechanistic models

Unmanned Aerial Vehicles (UAVs)

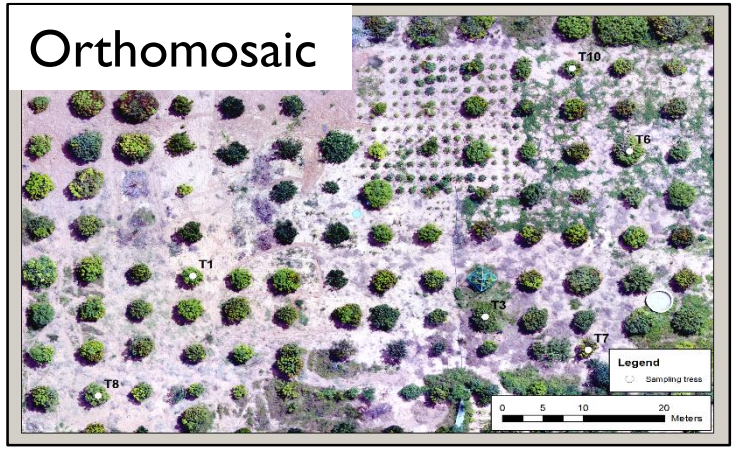
Flexible and low cost
VHR image (cm)
Structure-from-motion (DSM,3D)







Photogrammetry, Lisein et al. 2015



Forestry: tree detection and structure assessment - species classification – spatial gap - forest fire - forest health (review: Torresan *et al.* 2017)

Orchard application: tree structure, breeding programs, pruning impact
(Díaz-Varela *et al.* 2015; Torres-Sánchez *et al.* 2015; Jiménez-Brenes *et al.* 2017)

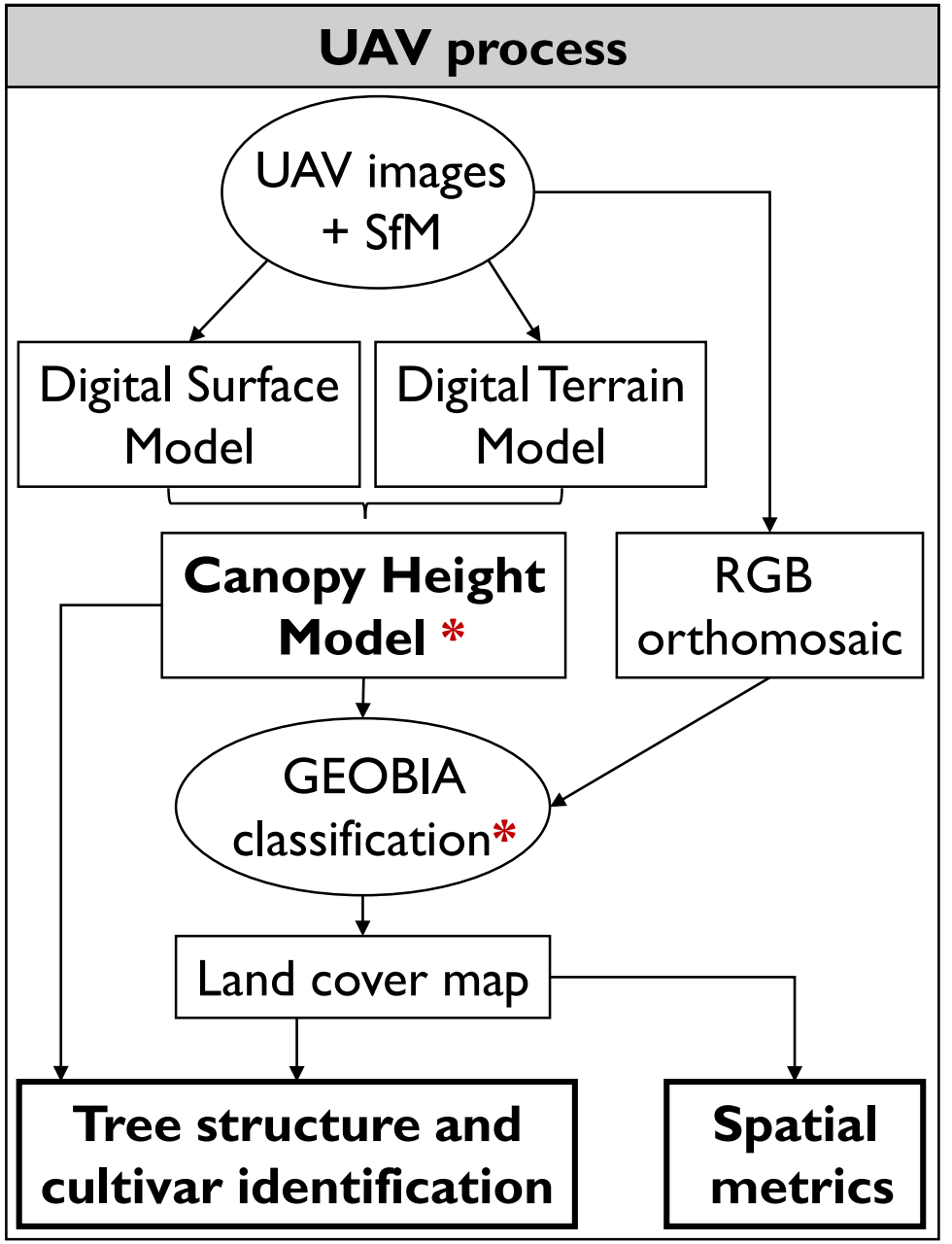
M&M (I): land cover and tree characteristics

GEOBIA : geographic object-based image analysis

eCognition

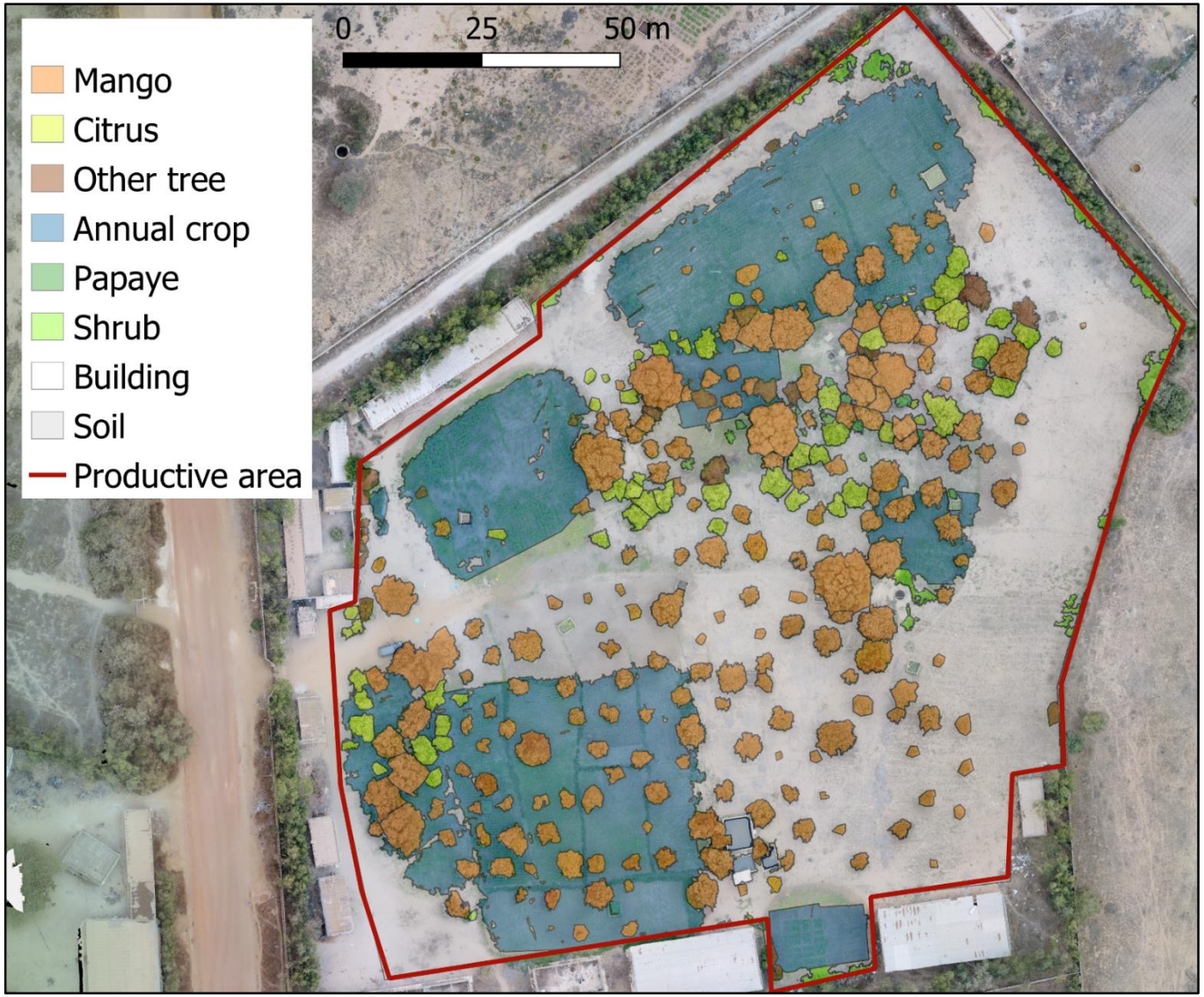
I. Multiresolution segmentation
II. Random Forest (RF) classification
    Level 1: plant species (10 classes)
    Level 2: mango cultivars (4 classes)
III. Post-treatment

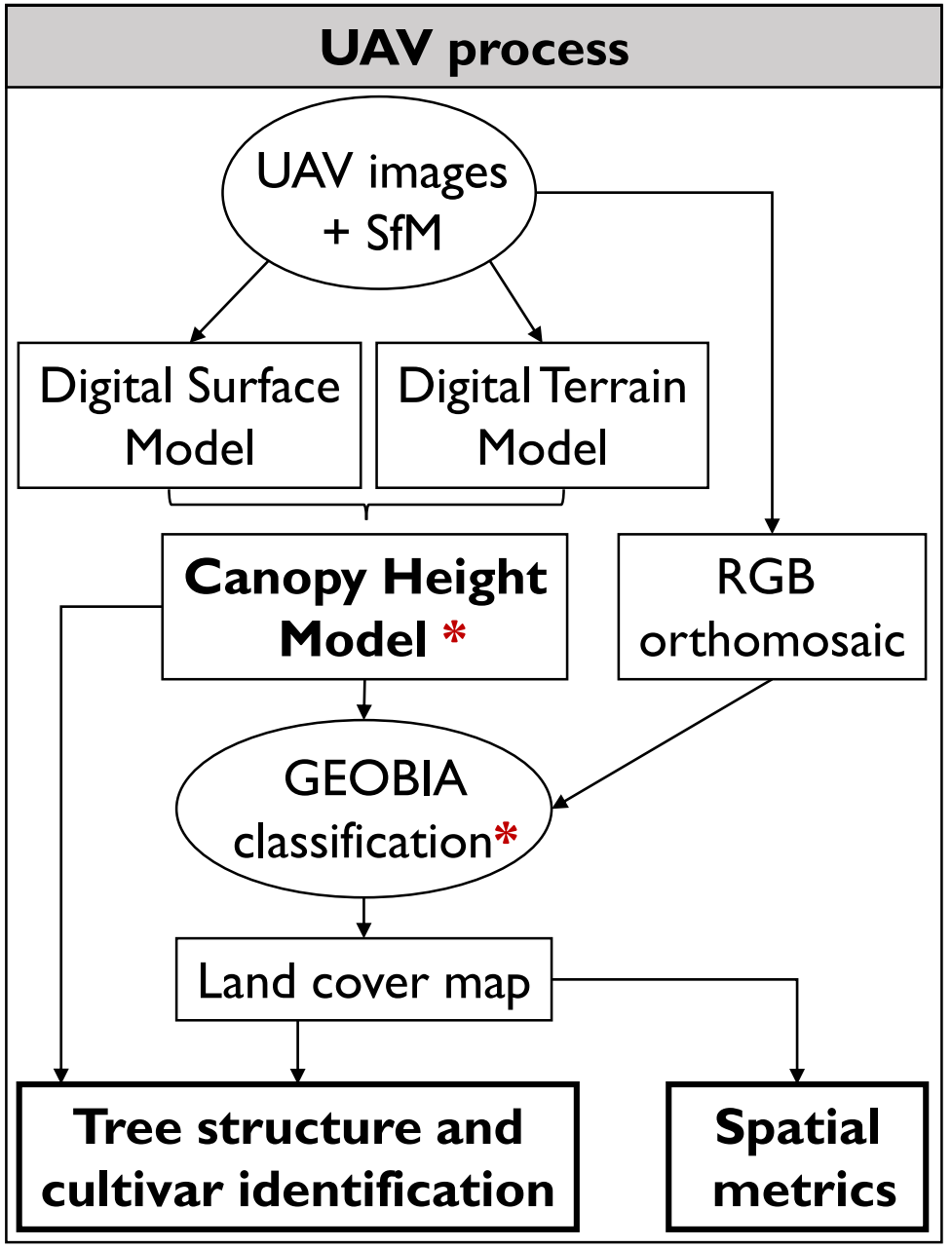
Land cover + tree crown delineation = tree structure parameters (tree height, crown area and volume)



*Validation steps

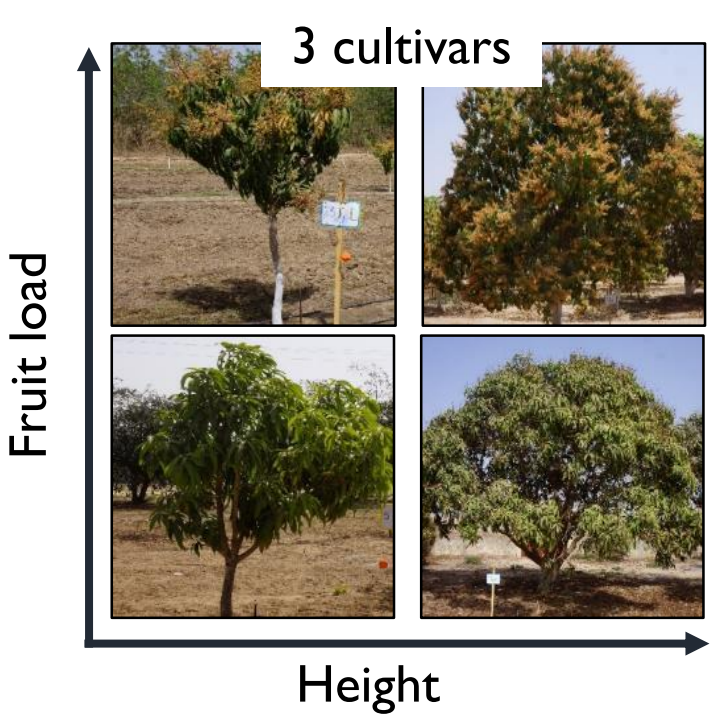
M&M (I): land cover and tree characteristics

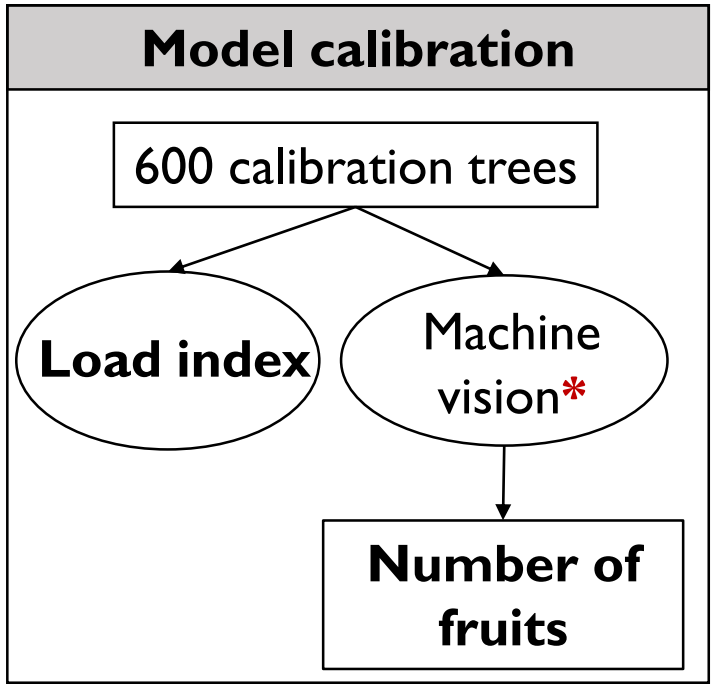


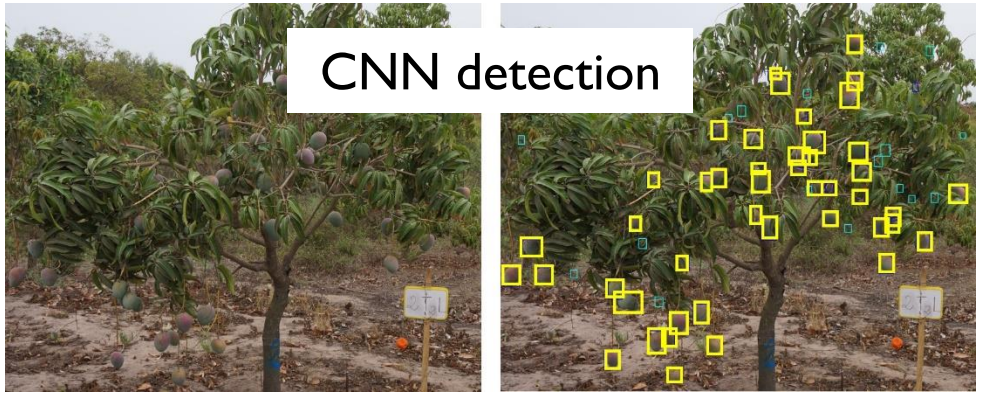


*Validation steps

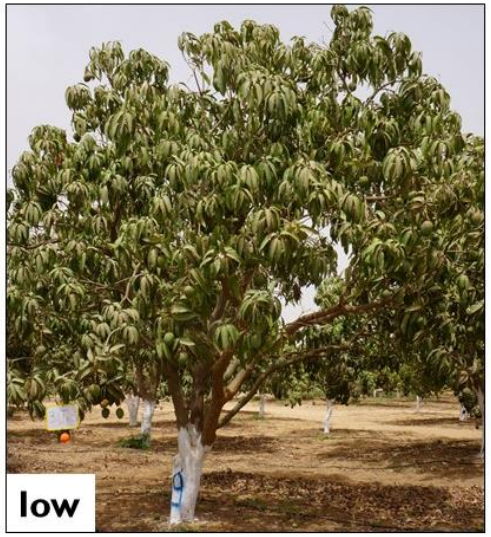
M&M (II): tree productivity

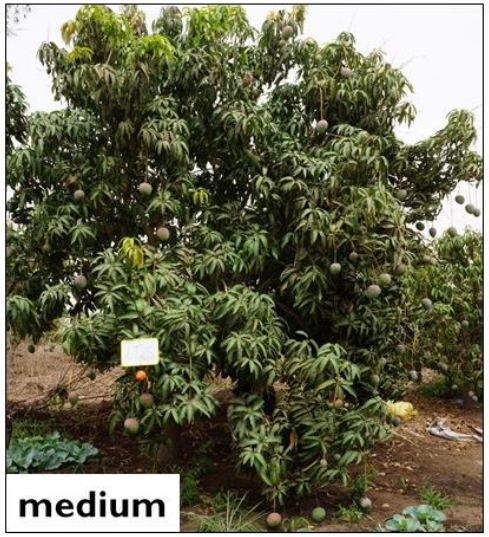


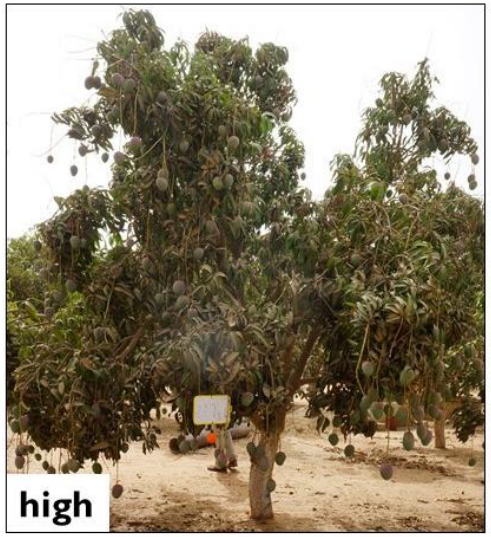


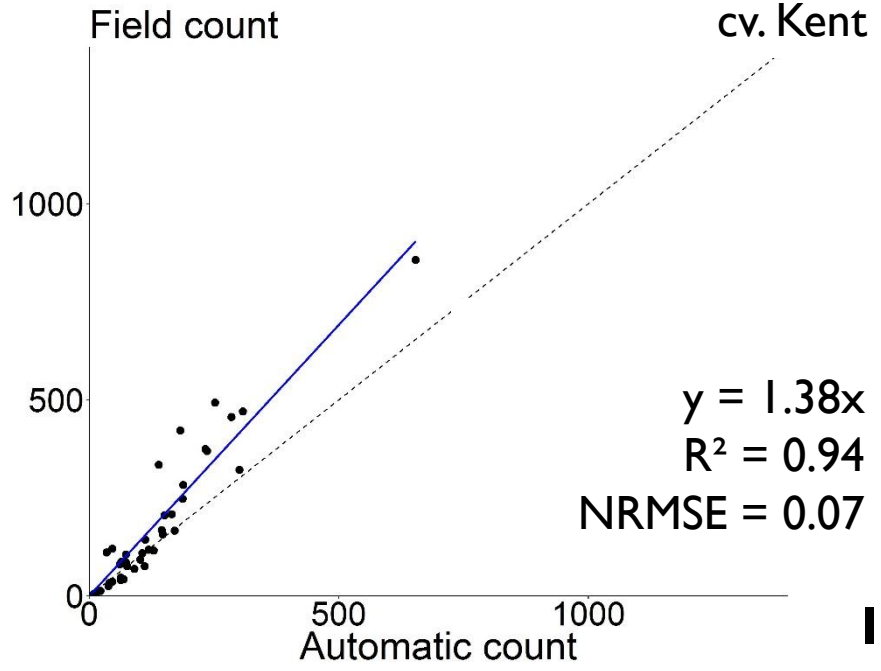


→ Actual number of fruits (calibration on 116 trees, NRMSE = 7%)



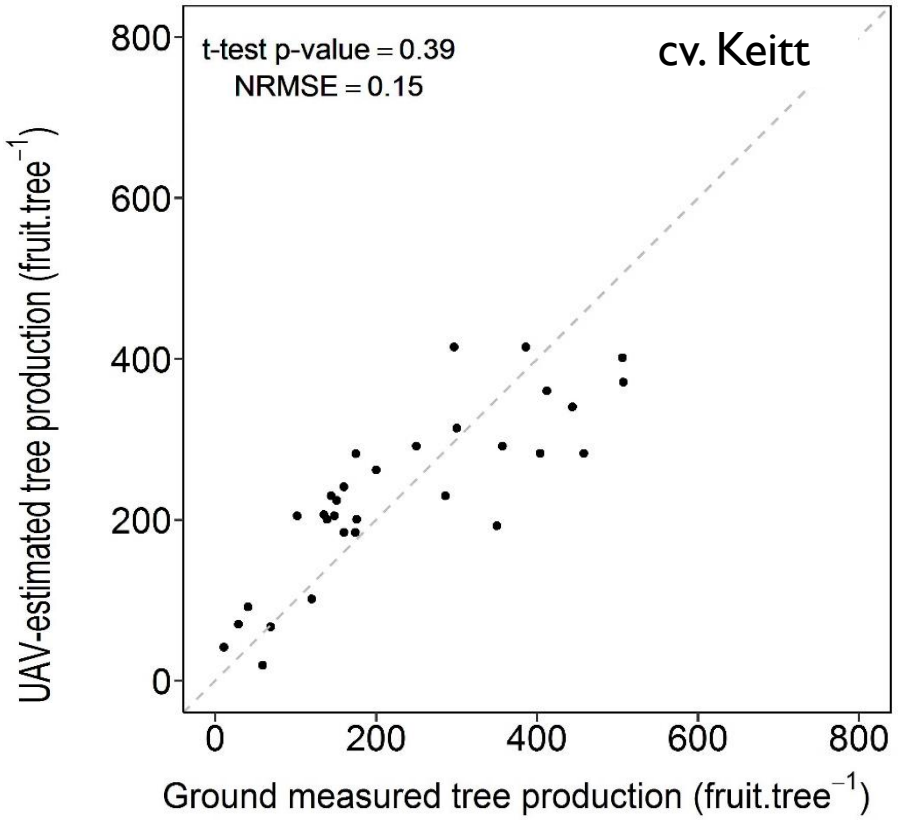




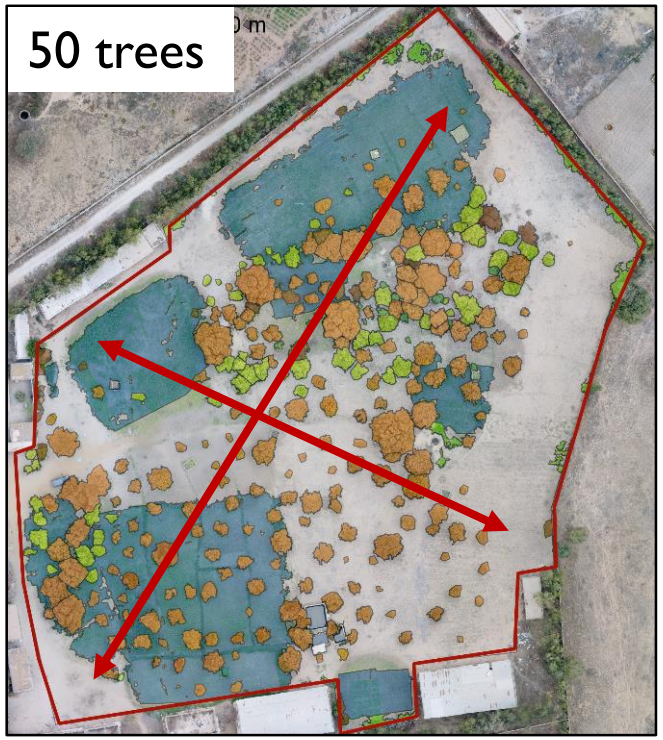


M&M (II): tree productivity

Cultivar	Selected model	R^2	RMSE%
'Kent'	$Y \sim LI + Area + Area^2 + Vol^2$	0.69	15.0
'Keitt'	$Y \sim LI + Area^2 + Vol + Vol^2$	0.57	15.0
'BDH'	$Y \sim LI + Height + Height^2$	0.65	8.0
Other	$Y \sim LI + Height^2 + Area + Area^2$	0.60	13.0



M&M (III): yield mapping



Field Data

28 mango orchards

Weighted load index per cv.

Model calibration

600 calibration trees

Load index

Machine vision*

Number of fruits

Tree production*

Orchard yield map

UAV process

UAV images + SfM

Digital Surface Model

Digital Terrain Model

Canopy Height Model *

RGB orthomosaic

GEOBIA classification*

Land cover map

Tree structure and cultivar identification

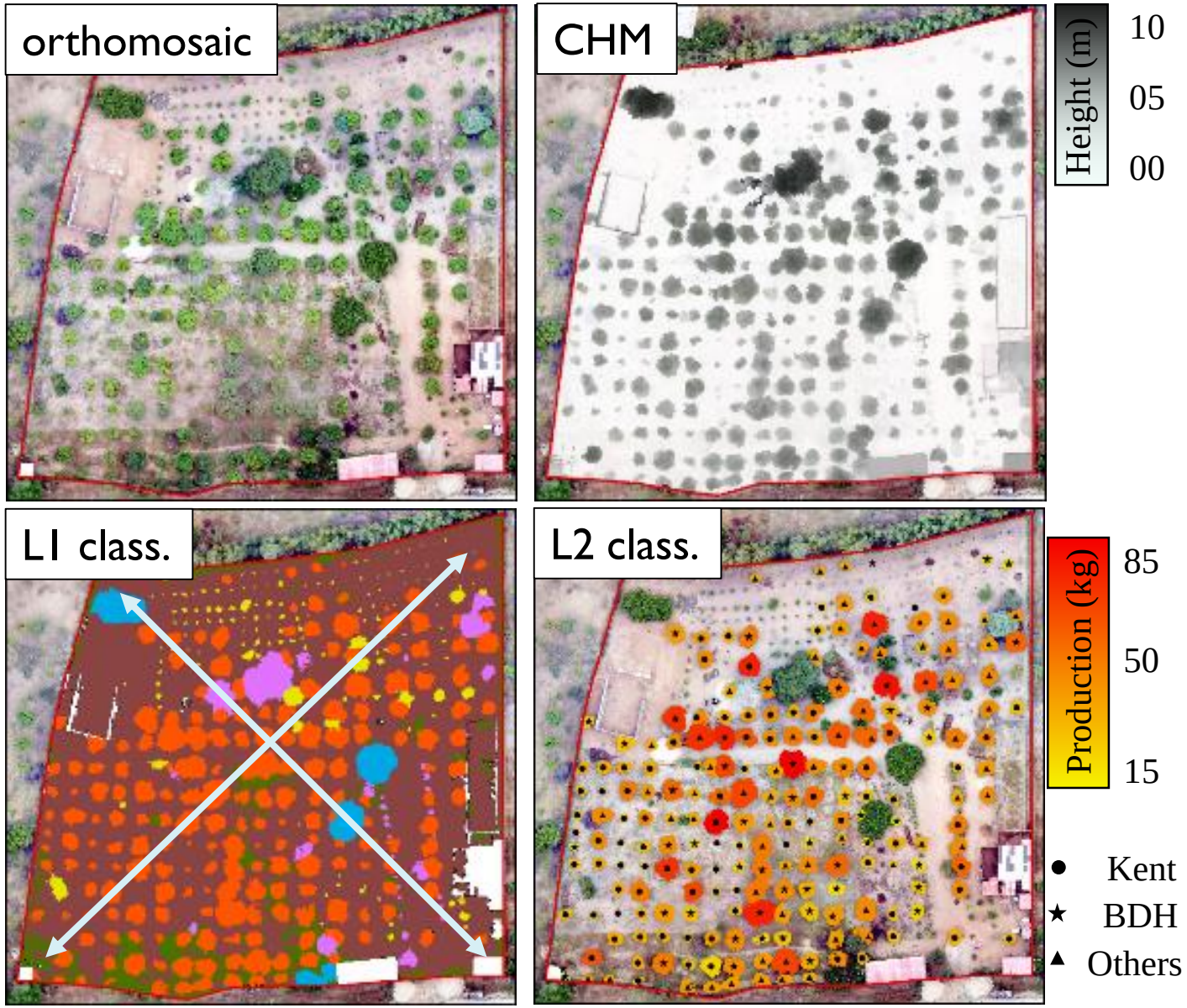
Spatial metrics

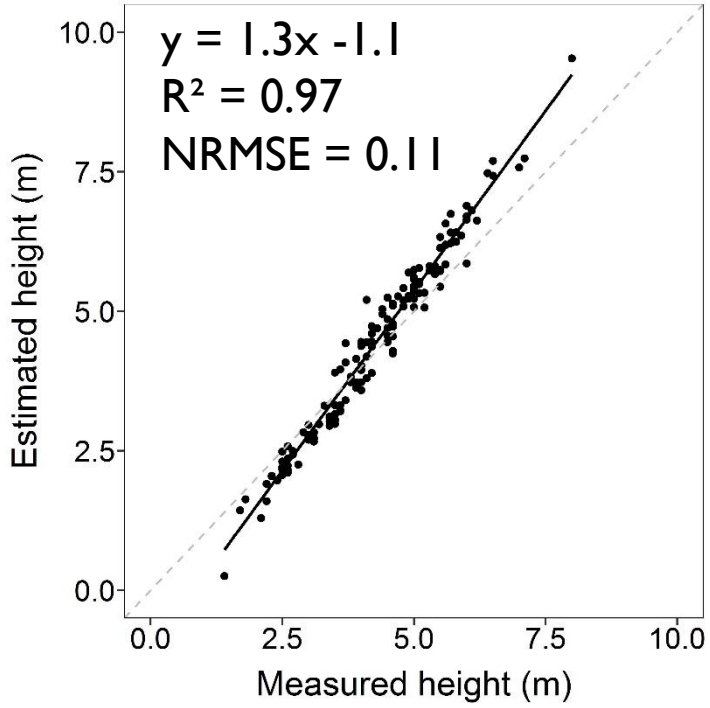
*Validation steps

Sarron et al. 2018

ArcGIS

Validation steps





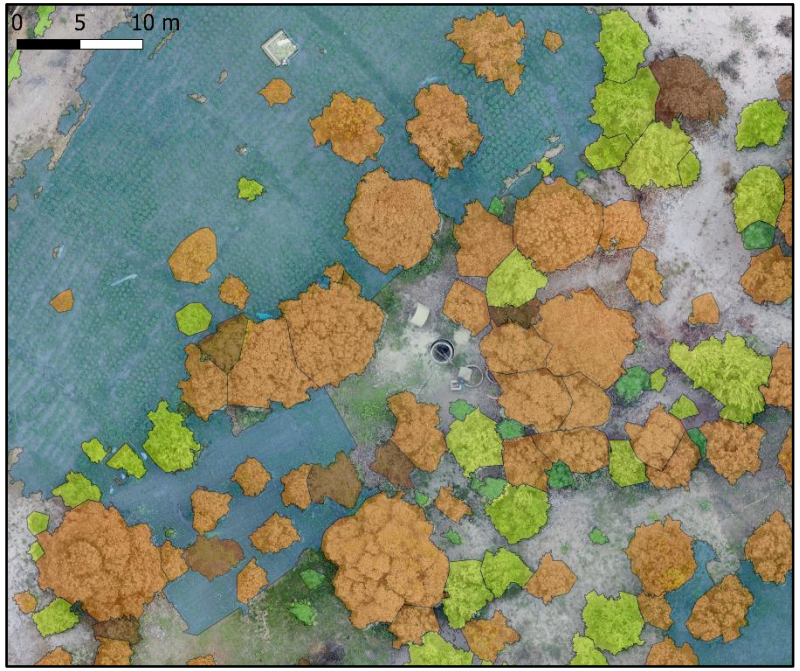
#	Area [ha]	Orchard yield [t.ha^{-1}]	
		Estimated	Producer
1	2.2	39.6	41.1***
2	2.1	14.6	6.9*
3	2.8	2.0	3.7*
4	2.2	6.7	1.1*
10	1.3	7.5	7.6***
11	1.5	11.2	10.5***

Classification overall accuracy = 0.89

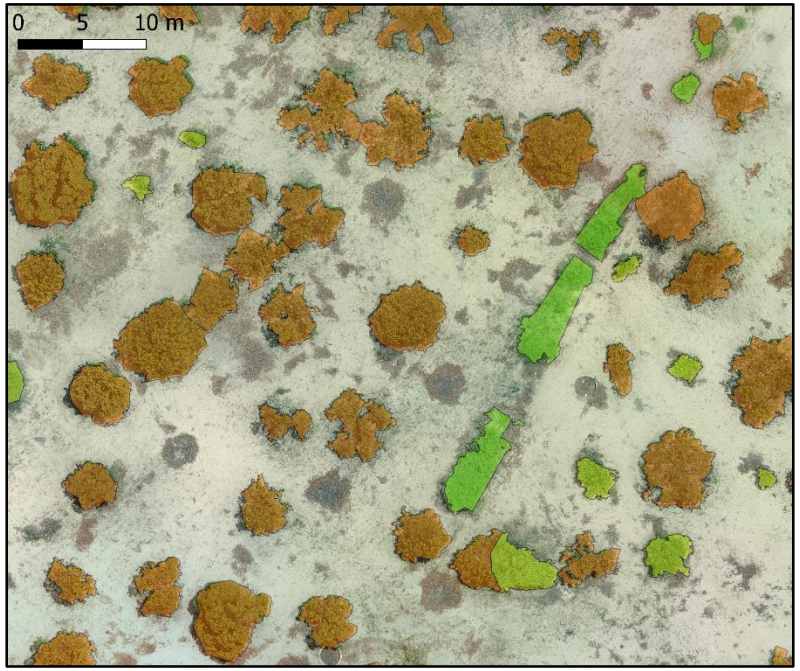
Reliability of data : * low; ** medium; *** high

Orchard productivity estimation (I)

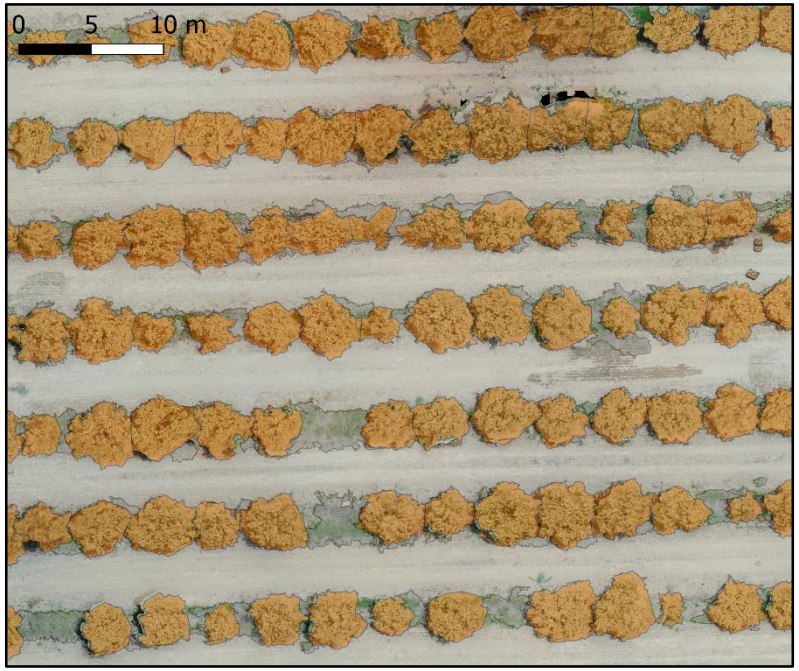
Agroforestry



Traditional



Intensive

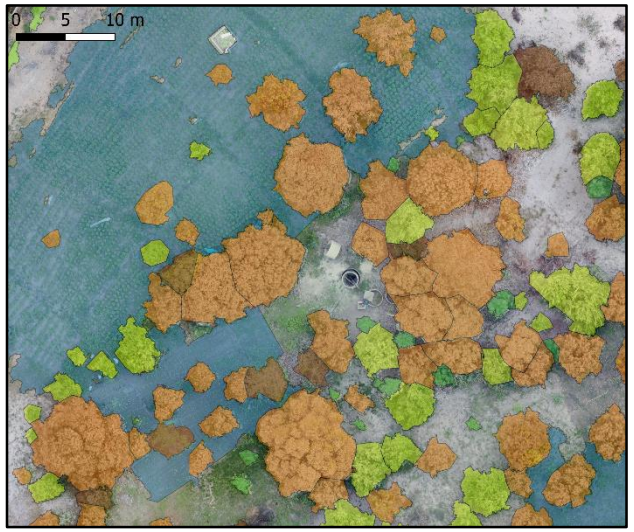


- Mango
- Citrus
- Other tree
- Annual crop
- Papaye
- Shrub
- Building

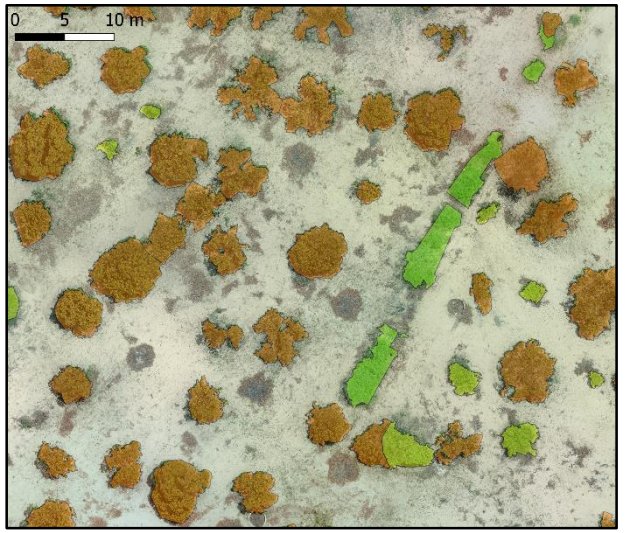
Orchard mango yield : kg of fruit per hectare
Orchard fruit load : kg of fruit per unit of crown volume
Tree production : average kg of fruit per tree

Orchard productivity estimation (II)

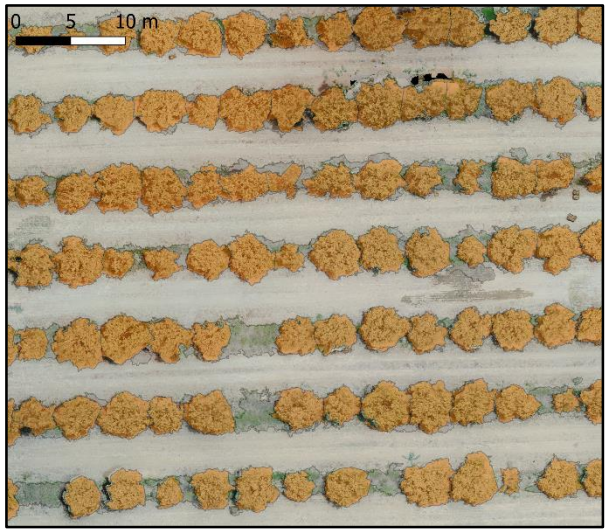
Agroforestry



Traditional



Intensive



Mango yield ($kg.ha^{-1}$)	**7626 b**	**4266 b**	**13347 a**
Fruit load ($kg.m^{-3}$)	**4.4 ab**	**2.6 b**	**6.9 a**
Tree production ($kg.tree^{-1}$)	**70.3 a**	**37.8 b**	**64.6 a**

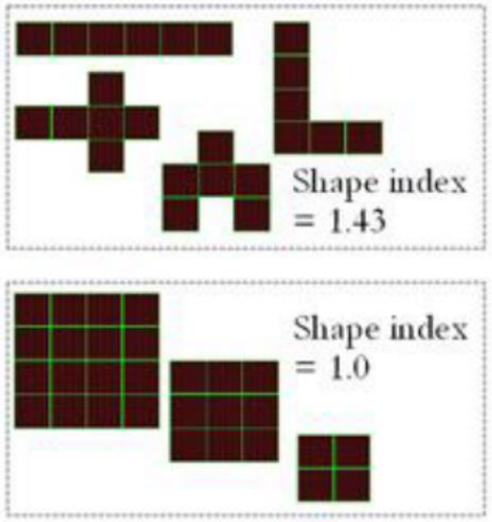
Landscape metrics

Fragstats 4.2

26 metrics at L1 classification
5 metrics at L2 classfication

Area, edge and shape

- Class or Total Area (CA/TA)
- Total Edge (TE)
- AREA (mn, sd)
- GYRATE (mn, sd)
- Perc. of land. (PLAND)
- Shape index (SHAPE) (mn, sd)
- Rela. circumscribing circ. (CIRCLE) (mn, sd)

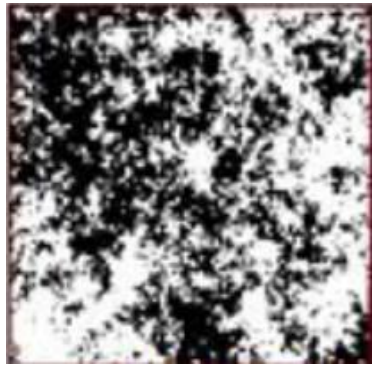


Aggregation

- Proximity index (PROX) (mean, sd)
- Nb of patches (NP)
- Patch density (PD)
- Aggregation index (AI)
- Land. shape index (LSI)

Diversity

- Patch richness (PR)
- Patch richness density (PRD)
- Shannon's diversity and evenness index (SHDI, SHEI)
- Simpson's diversity and evenness index (SIDI, SIEI)



Low aggregation

High aggregation

$$SHEI = -\frac{\sum_{i=1}^{m} P_i \times \ln(P_i)}{\ln(m)}$$

$$SIDI = 1 - \sum_{i=1}^{m} {P_i}^2$$

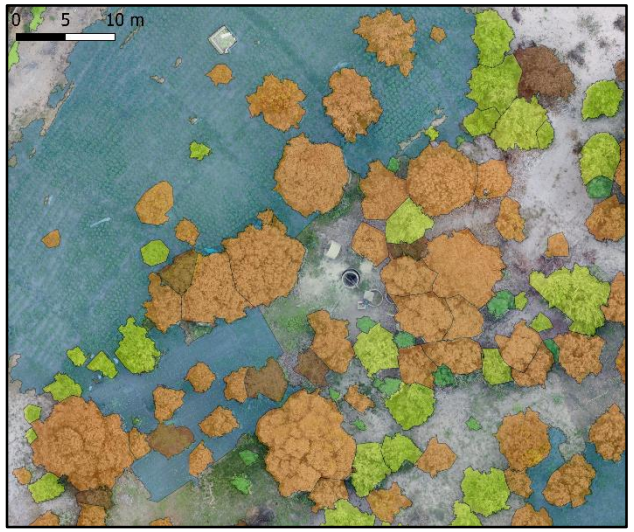
Plant diversity and productivity

Pearson correlation matrix, significantly correlated metrics (p-value < 0.05)

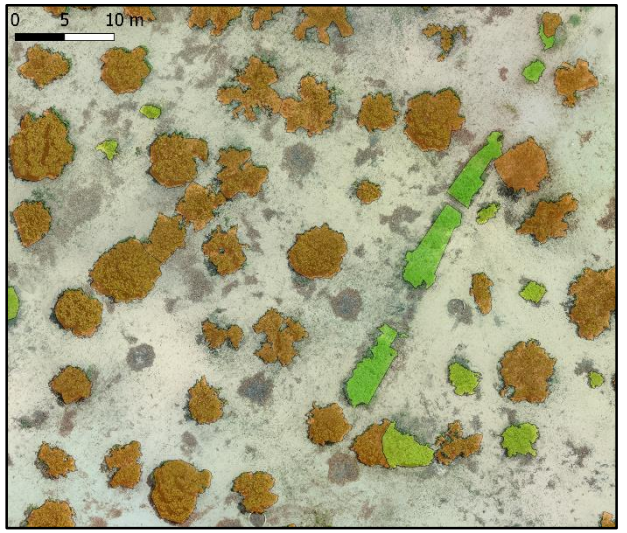
Mango yield (kg.ha^{-1})	Fruit load (kg.m^{-3})	Tree production (kg.tree^{-1})
Nb of specie (--)	**Nb of specie (--)**	SIEI (+)
Nb of cultivar (---)	Nb of cultivar (---)	**PLAND (citrus) (++)**
PLAND (citrus) (-)	PR (-)	**SHEI (+)**
PR (--)	SHDI (--)	
PRD (-)	**SHEI (--)**	
SHEI (++)	SIDI (--)	
SIEI (+)	SIEI (--)	

Orchard productivity estimation (II)

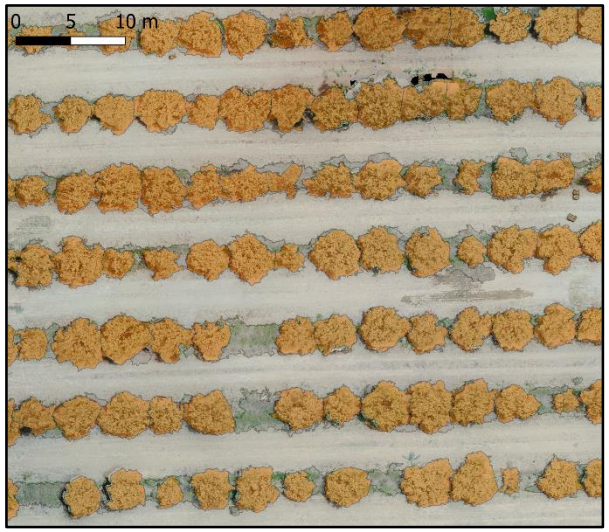
Agroforestry



Traditional



Intensive



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Fruit load ($kg.m^{-3}$)	4.4 ab	2.6 b	6.9 a
Tree production ($kg.tree^{-1}$)	70.3 a	37.8 b	64.6 a
Nb of specie	**4.3 a**	**3.8 a**	**1.2 b**
PLAND (citrus)	**4.4 a**	**1.2 b**	**0.3 b**
SHEI	**0.60 a**	**0.56 a**	**0.57 a**

Conclusion and perspectives

Land cover mapping and productivity estimation

1st methodological toolbox based on UAV for perennial production estimation
→ **Useful information for producer and researcher**

Limitations and improvement

Strong evaluation needed, computing time
Load index → automatic estimation ?
Deep learning ? Other sensor ?

Plant diversity and mango productivity

Evidence of correlations between plant diversity and productivity in mango-based orchard
→ **Highly diverse agroforest showed high productivity at mango tree scale**

Further work (in progress)

Complete assessment of effects of landscape, class and patch metrics on productivity
Integration of environment and management practices

Acknowledgments

4th World Congress on Agroforestry

cirad

E. Malézieux
E. Faye

ISRA

C.A.B. Sané
P. Diatta
J. Diatta